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Solar Powered Smart Waste Management using IoT

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ABSTRACT

Managing waste effectively remains a major hurdle in the pursuit of sustainable urban development. This paper proposes a solar-powered smart waste management system to improve the efficiency of urban waste collection. The system incorporates an Arduino Uno, dual ultrasonic sensors, a GSM module, a GPS unit, and Wi-Fi connectivity. One sensor monitors the waste level, while the other controls a servo motor for automated lid operation. Real-time bin status is transmitted to the ThingSpeak platform, enabling remote monitoring. When the bin reaches a specified threshold, an alert message with GPS location is sent via GSM to municipal authorities. An onboard LCD provideslocal status updates. The system is powered entirely by a solar panel, reducing reliance on conventional power sources. By integrating IoT, automation, and renewable energy, the proposed solution offers a sustainable and efficient approach to modern waste management.

Keywords— Arduino uno, Automated lid, GPS tracking, GSM module, Internet of Things (IoT), Smart Waste Management, Solar power, Sustainable Urban Development, ThingSpeak, Ultrasonic sensor.

INTRODUCTION

India's existing waste management systems face inefficiencies, largely due to the rapid population growth and the increasing volume of waste generated. Poor handling of waste poses serious risks to both environmental sustainability and public health. In the current scenario, enhancing waste management requires strategic planning and the integration of modern technologies. Population growth has greatly increased the amount of waste produced throughout the country [1]. Conventional systems suffer from multiple inefficiencies, such as overflowing bins, delayed collection, and fixed-route collection vehicles that do not account for actual bin status. These issues lead to unnecessary fuel consumption, increased labour costs, and overall inefficiency in waste collection operations.

The adoption of IoT-based technologies offers a promising approach to address these challenges. IoT facilitates real-time monitoring and communication between devices using embedded sensors, controllers, and cloud connectivity. Smart waste management systems leveraging IoT improve operational efficiency, reduce manual intervention, and support the development of cleaner, more sustainable urban environments.

This paper proposes a solar-powered smart waste management system that utilizes ultrasonic sensors, microcontrollers, a GSM module, GPS, and Wi-Fi for efficient bin monitoring and control. The system detects waste levels, automates lid operation, and sends real-time updates to the cloud. When a bin reaches capacity, an alert with GPS location is sent to the concerned authorities for prompt waste collection. The remainder of this paper is organized as follows: Section II reviews related work, Section III outlines the working principle and tools used in the proposed system, Section IV outlines the system's block diagram and its functional flow, Section V presents testing results, and Section VI concludes the paper.

LITERATURE SURVEY

Recent studies have explored the application of IoT technologies to address inefficiencies in waste management. In [1], an IoT based waste management system was proposed using NodeMCU, ultrasonic sensors, and a GPS module. This system not only monitors the garbage level in bins but also notifies collection authorities via online automation platforms like IFTTT and ThingSpeak, while a mobile application provides route optimization for collection trucks. Paper [2] proposed a smart waste management system using IoT to monitor dustbin levels and alert authorities when bins are nearly full. The system uses an ultrasonic sensor with NodeMCU and Arduino Uno to detect waste levels, which are visualized through the Blynk IoT application. When the bin exceeds 90–95% capacity, notifications are sent via email and SMS. This real-time monitoring enables timely cleaning, reducing overflow and improving urban hygiene.

Paper [3] emphasizes the need for automation in waste collection to reduce both manpower and fuel consumption. It presents a system that leverages IoT for monitoring garbage levels using a Wi-Fi module for data transmission, thereby mitigating unsanitary conditions caused by overflowing bins. In [4], a smart garbage bin is designed with a real-time monitoring capability that integrates sensors, a solar panel, and Arduino, relying on a wireless sensor network (WSN) to provide remote updates via Wi-Fi. This system is targeted at enhancing efficiency and ensuring a healthier environment. Paper [5] introduces a comprehensive waste collection management solution that employs sensor networks to capture large volumes of data, which are then analysed in a spatio-temporal context. This approach enables dynamic route management and waste collection optimization, validated through simulations using open data from Pune.

The authors in [6] proposed an IoT Garbage Monitoring System that automates waste monitoring and displays the status of bins through a web page, which forwards information to garbage collection services. This approach reduces manual monitoring and promotes timely waste collection through real-time updates. In [7], a smart garbage system was introduced to maintain the cleanliness of Accra, Ghana. The system uses ultrasonic sensors integrated with an AVR microcontroller and a SIM800L GSM/GPRS module to monitor waste levels. When a bin reaches capacity, it sends alerts to the collection unit. While the system enables real-time notifications, it does not include visual dashboards, relying on message alerts for communication.

A solar-powered compaction-based monitoring system was proposed in [8], where dustbin levels are indicated using LEDs, and once filled, a compaction module compresses the waste. A GSM module sends an SMS, and a GPS module provides the bin's exact location, helping authorities manage overflow issues promptly. However, real-time data display platforms were not integrated into this system. The study in [9] focused on developing a smart dustbin that opens its lid automatically upon human detection and sends SMS alerts when the garbage reaches a predefined threshold. The system, built using ultrasonic sensors and a GSM modem, continuously alerts staff until the bin is emptied. Although effective for notifications, the system does not utilize cloud-based platforms or web interfaces for data display.

Papers [10] proposed nearly identical systems featuring smart dustbins powered by solar energy with automatic solar tracking. These dustbins include ultrasonic and IR sensors, servo motors, and a GSM module. The lid operates automatically based on proximity sensing, and alerts are sent when the bin is full. Despite their energy efficiency and automation, these systems do not implement real-time monitoring on web-based dashboards, instead opting for SMS-based notifications.

PROPOSED SYSTEM

The proposed smart waste management system operates through a series of automated tasks designed to improve efficiency, hygiene, and sustainability in waste collection. An ultrasonic sensor mounted on the dustbin lid constantly tracks the fill level by calculating the gap between the sensor and the surface of the accumulated waste.Once the waste reaches a predefined threshold, the bin is considered full. A second ultrasonic sensor detects the presence of a person near the bin, triggering a servo motor to automatically open the lid, thus ensuring hands-free access and reducing human contact. Real-time bin's fill level is sent to the cloud using a NodeMCU ESP8266 module via the ThingSpeak platform, enabling remote monitoring. If the bin's fill level exceeds a critical, a GSM module sends an SMS alert to the concerned authority, including the bin's location determined by a GPS module. Additionally, an LCD display provides real-time local status updates for on-site personnel. The GPS data aids in route optimization for collection vehicles, reducing unnecessary trips, fuel consumption, and labour costs. This system not only prevents bin overflow and associated health risks but also contributes to smart and sustainable urban infrastructure by integrating IoT, automation, and solar energy solutions.

A. Hardware Tools

1. Solar Panel

Solar energy is converted into electricity using a compact polycrystalline solar panel. This panel serves as the primary power source for the system, ensuring energy autonomy in outdoor environments. It charges the connected battery via the solar charge controller, enabling sustainable operation without reliance on grid power.

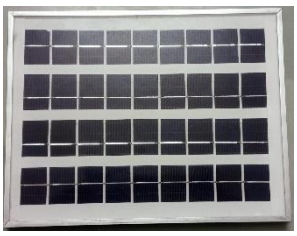

Fig. 1. Solar Panel

2. VRLA Lead-Acid Battery

A sealed, maintenance-free,VRLA battery is employed to the store energy harvested from the solar panel. It provides a stable power supply to the system during low-sunlight conditions or nighttime operation, ensuring continuous functionality of critical components.

Fig.2. Battery

3. Solar Charge Controller

The charge controller efficiently regulates the flow of power between the solar panel and the battery. It prevents battery overcharging and deep discharge by managing input/output voltage and current levels. The controller improves battery life and system reliability under variable solar conditions.

Fig.3. Solar Charge Controller

4. Regulated Power Supply

A Voltage-regulatedcircuit is integrated to deliver appropriate voltage levels to various modules. It steps down the 12V battery output to stable 5V and 3.3V levels required by microcontrollers, sensors, and communication modules. The RPS ensures safe and efficient operation of low-voltage components.

Fig.4. RPS

5. ESP8266 Wi-Fi Chip

The ESP8266 is a small and affordable Wi-Fi module that features an integrated TCP/IP stack, allowing seamless wireless communication with cloud platforms such as ThingSpeak. It is powered by a 32-bit Tensilica Xtensa L106 processor operating at 80 MHz, with 64 KB of instruction RAM and 96 KB of data RAM. The chip includes interfaces such as SPI, UART, I²C, and I²S. With a 10-bit ADC, up to 16 GPIO pins, and integrated RF components (balun, LNA, and power amplifier), it enables efficient and reliable wireless data transfer.

Fig.5. Wi-Fi Chip

6. Ultrasonic Sensors (HC-SR04)

Two HC-SR04 ultrasonic sensors are deployed in the system. The internal sensor monitors the fill level of waste inside the dustbin by measuring the distance to the garbage surface. The external sensor detects human presence near the bin, triggering the lid mechanism. These sensors operate through the emission of ultrasonic waves and calculating the return time of the reflected echo to determine object proximity.

Fig. 6. Ultrasonic sensor

7. Servo Motor (SG-90)

An SG-90 micro servo motor is used toregulate the automatic operation of the dustbin lid's opening and closing. It is activated by the external ultrasonic sensor upon detecting user presence. The servo operates with precise angular movement (typically up to 180°), ensuring smooth lid actuation with low power consumption.

Fig.7. Servo motor

8. Arduino Uno

The Arduino Uno microcontroller board handles local sensor data acquisition and servo control. It acts as a co-processor alongside the ESP8266, managing time-sensitive tasks such as ultrasonic distance measurements and lid movement. It also communicates with the Wi-Fi chip to relay bin status and events to the cloud.

Fig.8. Arduino uno

B. Software Tools

1.Arduino IDE

The Arduino Integrated Development Environment (IDE) is an open-source software platform designed for coding, compiling, and uploading programs to Arduino-compatible microcontrollers. It supports programming in C and C++, provides features like syntax highlighting and auto-completion, and includes a built-in Serial Monitor for real-time debugging and data visualization. The IDE is cross-platform, working on Windows, macOS, and Linux, and is widely used due to its user-friendly interface and extensibility with libraries and community-contributed plugins.

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Fig. 9. Arduino IDE

2.ThingSpeak Cloud

ThingSpeak is a cloud-driven IoT analytics platform that facilitates real-time data collection, visualization, and analysis. It supports data transmission from devices using HTTP and MQTT protocols and allows integration with MATLAB for advanced analytics. ThingSpeak is used for remote monitoring, data logging, and triggering actions based on sensor inputs, making it ideal for smart system applications requiring wireless data handling and cloud interaction.

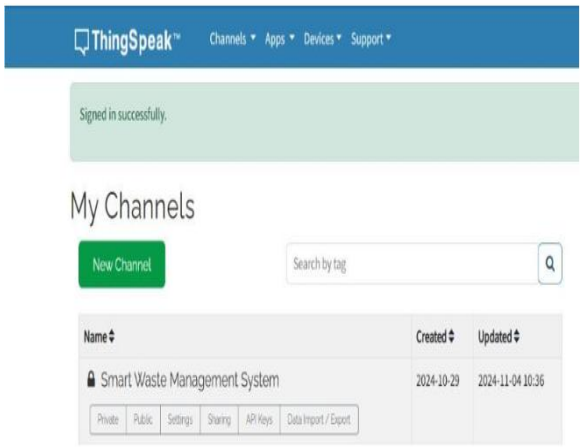

Fig.10. ThingSpeak platform

BLOCK DIAGRAM

Fig. 11 illustrates the block diagram of the complete smart waste management system. Thissystem utilizes a renewable energy-based power supply architecture comprising a photovoltaic panel, a sealed lead-acid battery, and a solar charge controller. This configuration is designed to ensure uninterrupted and regulated power delivery to all electronic modules under varying environmental conditions, including periods of low solar irradiance.

A solar panel is interfaced with the solar input terminals of a solar charge controller. The controller regulates the energy harvested from the panel and concurrently charges a VRLA battery connected across the designated battery terminals. Overcharging and deep discharging of the battery are actively prevented by the controller's internal protection circuitry.

The load terminals of the charge controller are connected to a Regulated Power Supply (RPS) board. This board steps down the 12 V input to a stable 5 V DC output, which is subsequently distributed to all low-voltage modules within the system. This regulated output ensures consistent operation of microcontrollers, sensors, and communication modules.

One HC-SR04 ultrasonic sensor is positioned at the front of thebin to detect the presence of a person approaching the it. The sensor continuously emits ultrasonic pulses and listens for their echo to measure the distance of nearby objects. When the measured distance falls below a predefined threshold, the microcontroller interprets this as a person intending to use the bin.Upon detection, the microcontroller generates a control signal that is sent to a servo motor (SG90) connected to the dustbin lid. The servo receives a PWM (pulse-width modulation) signal and rotates to a specific angle to open the lid. After a fixed time delay, the servo is instructed to return to its initial position, thereby closing the lid.

To monitor the waste level continuously, an ultrasonic sensor is mounted inside the bin and interfaced with the Arduino Uno microcontroller. This sensor determines the gap between the waste and the lid, which is then used to calculate the fill level of the bin. The Arduino processes the sensor data and transmits it to a cloud-based Internet of Things (IoT) platform, ThingSpeak, via the ESP8266 module. This moduleestablishes a wireless connection to a nearby Wi-Fi network. The Arduino sends HTTP requests using AT commands through the ESP8266 module, which forwards the data to the predefined ThingSpeak channel using its API key. This enables remote visualization of real-time bin levels through graphs and dashboards on the ThingSpeak server.

When the bin reaches a predefined full level, the Arduino initiates an alert sequence. It communicates with the SIM800C GSM module and simultaneously, it retrieves the current GPS coordinates from the NEO-6M GPS module, which continuously sends location data to the Arduino. Upon detecting a full bin, the system extracts the latest latitude and longitude from the GPS module and formats an alert message. This message includes a predefined text along with the corresponding GPS coordinates. The Arduino then instructs the SIM800C module to send this information as an SMS to a registered mobile number using AT commands. The calculated fill level is simultaneously displayed on a 16×2 LCD screen interfaced with the Arduino. This provides immediate visual feedback to nearby users or personnel, indicating messages such as “Bin is Full” based on threshold conditions.

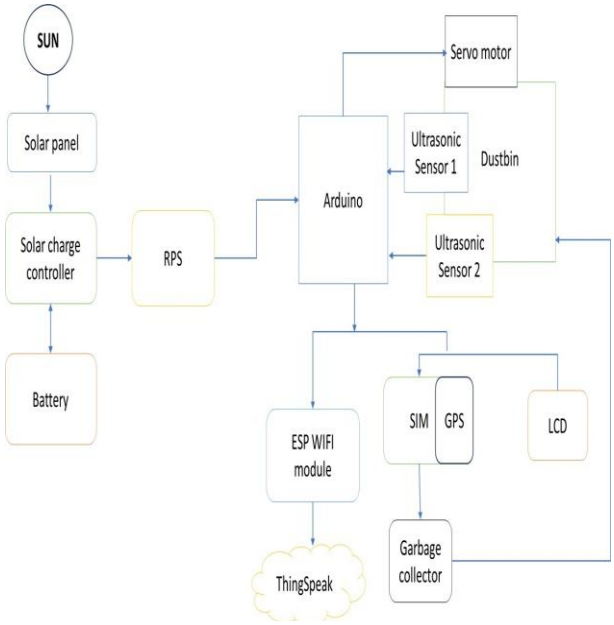

Fig.11.Block diagram of solar powered smart waste management

RESULTS AND DISCUSSIONS

A functional prototype of the solar-powered smart waste management system was developed and tested to demonstrate its core features.The experimental setup, as shown in Fig. 12, integrates all key components including the solar power supply, microcontrollers, sensors, communication modules, and display interfaces.

The bin's lid operation was automated using a servo motor mechanism. Fig. 13 illustrates the automated opening and closing of the lid, which is triggered by the detection of a nearby user. The real-time status of the lid, whether open or closedis simultaneously displayed on an onboard LCD, as depicted in Fig. 14, allowing for user awareness and ease of local monitoring.

Waste level monitoring was achieved using an ultrasonic sensor, with real-time data transmitted to the ThingSpeak cloud platform. Fig. 15 presents the dashboard view of the bin’s fill level, enabling remote access for municipal authorities. Additionally, the current fill level is shown on an onboard LCD for on-site personnel, as illustrated in Fig. 16.

Upon reaching the predefined threshold, the system triggers an SMS alert with GPS location of bin. This feature is demonstrated in Fig. 17, ensuring timely waste collection and preventing overflow. To further aid the collection process, the shortest route to the bin is visualized through a Google Maps interface, as shown in Fig. 18, enabling efficient navigation for waste management personnel.

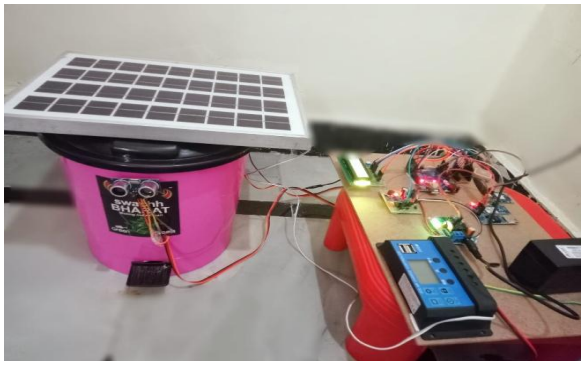

Fig.12. Experiment setup of solar powered smart waste management

Fig.13. Automated lid open and close mechanism of the bin

Fig.14. Bin lid's open and close status on LCD

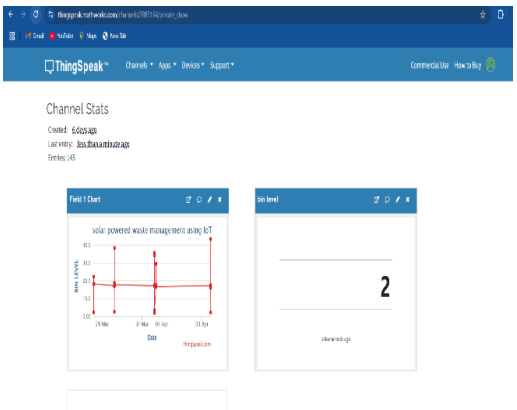

Fig.15. Real-time bin level indication on ThingSpeak dashboard

Fig.16. Waste level on an onboard LCD

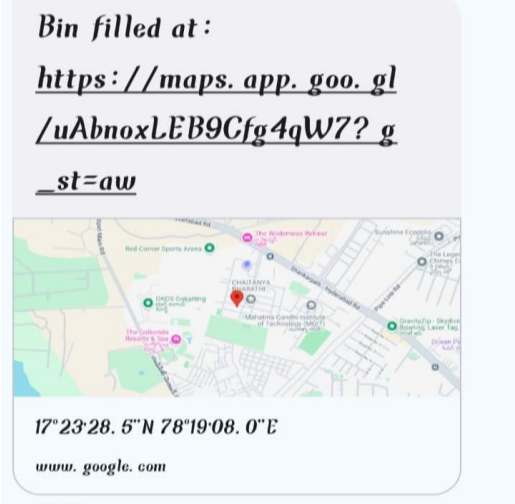

Fig.17. SMS Alert With Bin Location On Full Capacity

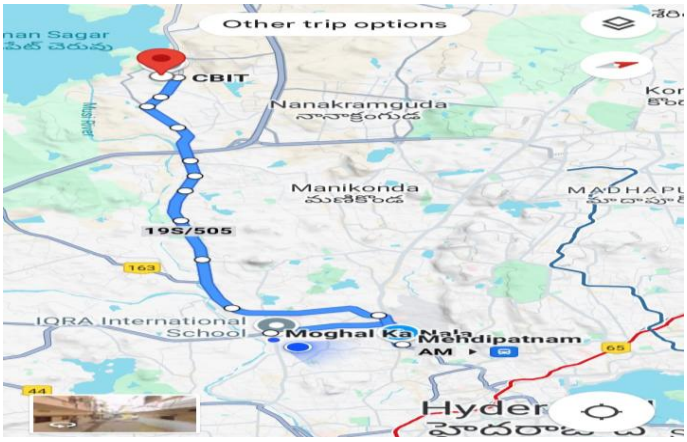

Fig.18. Google Maps interface illustrating the optimized route to the dustbin

CONCLUSION

This paper presents the design and development of a solar-powered smart waste management system using IoT technologies for efficient, hygienic, and sustainable urban waste collection. The prototype integrates key components such as ultrasonic sensors for real-time waste level monitoring, a servo motor for automated lid operation, esp8266 WIFI chip for cloud data transmission, GSM and GPS modules for alert messaging with location tracking, and an

onboard LCD for local status display. The system ensures timely alerts when the bin reaches full capacity and provides optimized routing using Google Maps, thereby reducing manual intervention, fuel consumption, and operational costs.

The successful testing of the prototype demonstrates that the system functions effectively and can contribute to the development of smart city infrastructure.

REFERENCES

[1]. Palak Jain, Taneesha Chaudhary, and Sachin Gajjar, "Design and Development of Smart Waste Management System," 2023 International Conference on Communication System, Computing and IT Applications (CSCITA), Ahmedabad, India, 2023, pp. 198–203.
[2]. Malathy Sathyamoorthy, Ajeet Kumar Sharma, C. N. Vanitha, Bhisham Sharma, Praveen Raja S, and Subrata Chowdhury, "Smart City Waste Management System using IOT," 2023 6thInternational Conference on Information Systems and Computer Networks (ISCON), Mathura, India, 2023, pp. 1–6.
[3]. K. Rajesh, S. Janani, B. Rohini, S. Rajendran, R. Agalya, and A. Ramkumar, "Intelligent Garbage Monitoring System Using IoT,"2021 2nd International Conference on Electronics and Sustainable Communication Systems (ICESC), Coimbatore, India, 2021, pp. 717-722.
[4]. C. Vinothini, M. Tharini, G. Saranya Sasikumar, K. Ikash, and R. Karthick, "IoT based Smart Garbage System Powered with Solar Cell," International Journal of Engineering Research & Technology (IJERT), vol. 9, no. 1, pp. 418-421, Jan. 2020.
[5]. Gopal Kirshna Shyam, Sunilkumar S. Manvi, and Priyanka Bharti, "Smart Waste Management using Internet-of-Things (IoT)," 2017 International Conference on Internet of Things and Applications (IOTA), Pune, India, 2017, pp. 199–204.
[6]. S. M. Chaware, S. Dighe, A. Joshi, N. Bajare, and R. Korke, "Smart Garbage Monitoring System using Internet of Things (IOT)", International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering (IJIREEICE), Jan. 2017, vol. 5, no. 1, pp. 74–76.
[7]. Prince Kelvin Owusu, "Smart Garbage Monitoring System using Internet of Things," Middle East Journal of Applied Science & Technology (MEJAST), vol. 3, no. 2, pp. 74–82, Jun. 2020.
[8]. Poornima G R, Bindu Shree N, Aishwarya S, and Nayana K M, "Solar Photovoltaic Powered Smart Garbage Monitoring System Using GSM/GPS," Proceedings of the IEEE Conference, 2018, pp. 1–6.
[9]. Kunal Dalvi, Prathamesh Tharwal, Nikhil Chaudhari, Yatish Mhatre, and Supriya Shigwan, "Solar Powered Dustbin for Efficient Waste Management", International Journal of Emerging Trends in Engineering and Technology (IJETET), 2025, Vol. 12, Issue 4, pp. 45–50.
[10]. S.V. Patil, Omkar Jagdale, Prathmesh Pathari, Anish Patil, and Darshan Raut, "Smart Dustbin Using Automatic Solar Tracker", International Journal of All Research Education and Scientific Methods (IJARESM), vol. 10, no. 4, pp. 1731–1736, April 2022.